CHARACTERIZING STIFFNESS OF CLSM USED FOR BACKFILL UNDER APPROACH SLAB

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ABSTRACT

In this study, flowable backfill(so-called CLSM) made with weathered granite soil is tested to provide basic engineering properties that can be used as design input to overcome settlement problems under bridge approach slab due to low stiffness of backfill which is generated by porosity of the backfill soil. For design purpose, a proper mixing ratio is developed first. Then several test methods including FF/RC, PMT and LDWT including axial compression test are adapted for checking stiffness and measuring axial compressive strength of the material separately that can be used for design values

1. INTRODUCTION

Most bridge structures experience uneven settlements and faults near joints between bridges and approach slabs. It has been considered that the faults and uneven settlements are generated due to shortage of mechanical compaction energy onto the backfill soil. However, even well compacted soil used as subgrade in embanking road can be deformed somehow under traffic load so that faulting and vertical settlement cannot be controlled within limit criteria for keeping comfortable driving. Major reason of generating deformation in the subgrade and/or backfill soil is contributed to voids in the structure that cannot be deleted thoroughly by mechanical compaction (Figure 1). Therefore a new material, but cheap and relatively abundant and easy to obtain, must be considered as replacing material for the compacted soil and/or backfill under approach slab.

CLSM(Controlled Low Strength Material) can be used as the replacing material for the compacted soil because it has characteristics of self-leveling, self-compacting, flowability and controllable strength etc.. The CLSM is considered to prevent settlements and cracks on the pavement generated by deformation of the backfill and embankment material. CLSM is made of fly ash, sand, Portland cement and water with designed mixing ratio so that it can have enough flowability at very early stage of curing age, but it can take strength and stiffness with time.

In this study, several tests are performed to verify the applicability of CLSM as replacement of the compacted soil in embankment and/or backfill below approach slab in order to reduce vertical

settlements and faults around joints between the bridge and the approach slab. Free-Free Resonant Column (FF-RC) test, unconfined compression test (UCT), light weight deflectometer test(LWDT) and Pressuremeter test (PMT) are used to investigate characteristics of stiffness and compressive strength of CLSM with aging days using designed mixing ratio.

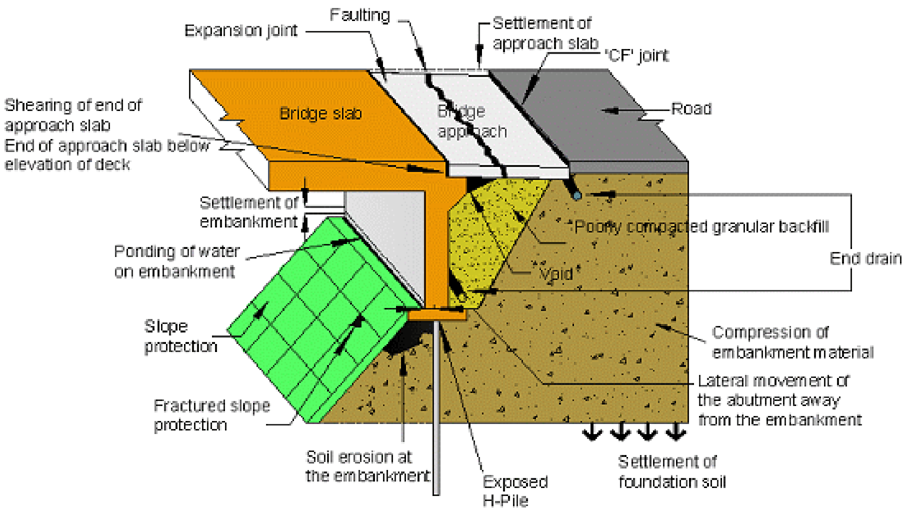


Figure 1. Reasons of generating settlements and bumps near the bridge abutment [3].

2. MATERIAL PROPERTIES OF CLSM WITH WEATHERED GRANITE SOILS

Weathered granite soils are abundant in the field of construction site in Korea so that they are used as the backfill and embankment soils. Thus, in this study, the use of the weathered granite soil is planned to be adapted as a compartment in CLSM instead of expensive sand. The CLSM is going to be used as replacement of backfill soil. The CLSM is prepared by mixing dried and sieved ($P_{200}<x<P_{10}$) weathered granite soil with 2~5 % of the Portland cement and some amount of fly ash and water. A proper range of mixing ratio was designed with different amount of each compartment materials. Characteristics of weathered granite soil used for CLSM mixing are summarized in Table 1. Properties of sand used for CLSM mixing used for comparative study are summarized in Table 2. Properties of fly ash used for CLSM are summarized in Table 3.

Table 1. Characteristics of weathered granite soil used for CLSM mixing

Weathered Granite Soils	G_s	$\gamma_{d-\max}$ (kN/m^3)	OMC (%)	C_c	C_u	P_{200} (%)	C (kPa)	φ (deg)	PI	USCS
	2.66	18.35	10.1	1.1	7.1	9.15	79.5	38.9	N.P	SW

Table 2. Properties of sand used for CLSM mixing

G_s	Particle size	%<300 μm	k (cm/sec)	USCS
2.6	300 ~ 600 μm	Less than 6 %	$3\sim4\times10^{-3}$	SM

Table 3. Properties of fly ash used for CLSM

	S_iO_2 (%)	water (%)	Ig. loss (%)	Density (g/cm^3)	Fineness		Flow (%)	Activity %		
					45μm Remaining (%)	Spec. Surf. Area (cm^2/g)		age 28day	age 91day	
Fine-II Criteria	>45	<1.0	<5.0	>1.95	<40	>3000	>95	>80	>90	KS L 5405 Criteria
values	53.4	0.1	3.8	2.3	14.0	3830	102	93	93	

Table 4. UCS and elastic modulus with mixing ratio and flowability for sand CLSM

Serial No.	Mixing Raio (%)				Flowabiliy (mm)		UCS (kgf/cm2)	E (MPa)
	Cement	Fly ash	Water	Sand	ASTM D 6103	JHS A 313		
# 1	2.5	15.7	18.2	63.6	286	257	3.42	1766.5
# 2	3.0	15.2	18.2	63.6	295	256	4.30	2292.3
# 3	3.5	14.7	18.2	63.6	288	268	4.49	2628.4
# 4	4.0	14.2	18.2	63.6	289	256	5.10	3008.8
# 5	4.5	13.7	18.2	63.6	290	265	8.33	3921.5
# 6	5.0	13.2	18.2	63.6	285	259	7.12	3554.9
# 7	5.5	12.7	18.2	63.6	280	265	8.60	4036.5
# 8	6.0	12.2	18.2	63.6	291	254	11.64	4294.8
# 9	6.5	11.7	18.2	63.6	284	267	14.98	5062.4
# 10	7.0	11.2	18.2	63.6	274	250	12.48	5724.7

Mixing ratio for CLSM was decided based on ASTM D 6103 to get enough flowability so that the CLSM should have diameter bigger than 20cm when it was poured on a flat table after mixing. The decided mixing ratio of CLSM mixed with weathered granite soils of about 10 % amount showed 7.9 % bigger percent of water and fly ash than that of CLSM mixed with sand to get enough flowabilty. It is probably due to amount of fines less than 0.075mm size. The designed mixing ratio is determined as

shown in Table 4 and Table 5 for sand and weathered granite soil CLSM respectively. UCS and Elastic modulus were obtained from UCT and FF-RC Test which will be explained in detail later.

Table 5. UCS and elastic modulus with mixing ratio and flowability for weathered granite soil CLSM

Serial NO.	Mixing Ratio (%)				Flowability (mm)		UCS (kgf/cm2)	E (MPa)
	Cement	Fly ash	Water	W. soil	ASTM D 6103	JHS A 313		
# 1	2.5	23.6	26.1	47.8	273	237	3.42	985.9
# 2	3.0	23.1	26.1	47.8	266	230	4.77	1354.8
# 3	3.5	22.6	26.1	47.8	268	232	5.65	1359.9
# 4	4.0	22.1	26.1	47.8	282	239	6.07	1414.1
# 5	4.5	21.6	26.1	47.8	255	234	5.86	1601.7
# 6	5.0	21.1	26.1	47.8	268	242	8.02	1673.9
# 7	5.5	20.6	26.1	47.8	268	238	8.47	1936.7
# 8	6.0	19.6	26.1	47.8	259	228	7.64	2202.8
# 9	6.5	19.1	26.1	47.8	252	231	9.63	2486.3
# 10	7.0	18.6	26.1	47.8	238	211	12.85	2578.5

3. MECHANICAL TESTS IN LABORATORY

With use of designed mixing ratio, CLSM samples were prepared and cured in the air. UCT (Figure 2) and FF-RC (Figure 3) were performed first in the laboratory to investigate strength and stiffness of the CLSM samples with curing age. From the UCT tests, a proper range of mixing ratio was obtained first.

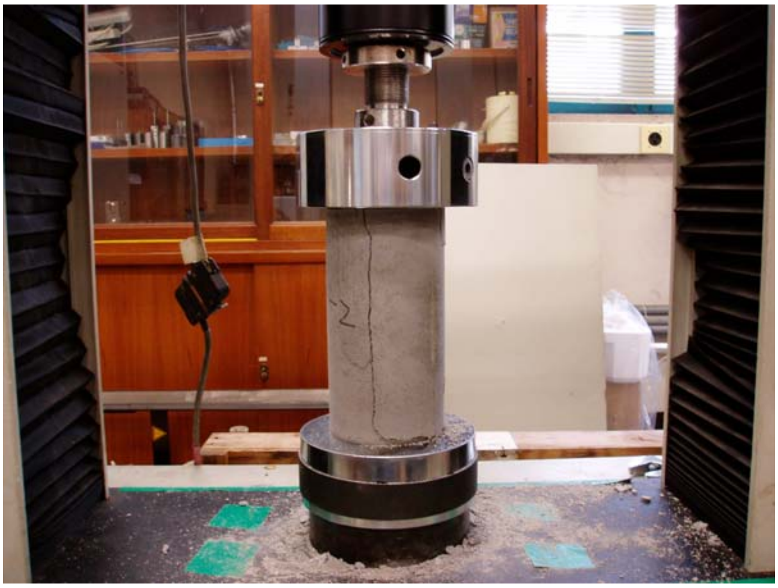


Figure 2. Schematic view of UCS test.

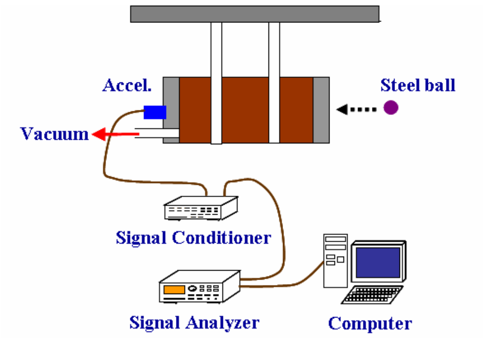


Figure 3. Schematic view of FF-RC test.

In FF-RC tests, compressive waves are generated by impacting surface of the CLSM samples using a steel ball from a given height. Then a resonance frequency (f_c) of the CLSM sample can be obtained from FFT (Fast Fourier Transfer) analysis as shown in Figure 4. A relation between the resonance frequency and the velocity of the compressive wave (v_c) under unconfined condition is as follows:

$$V_c = f_c \times \lambda = f_c \times 2l$$

where f_c = resonance frequency, λ = wave length.

Elastic modulus of the sample can be obtained using the following equation:

$$E = \rho \cdot V_c^2$$

where ρ = density of the material used in the sample

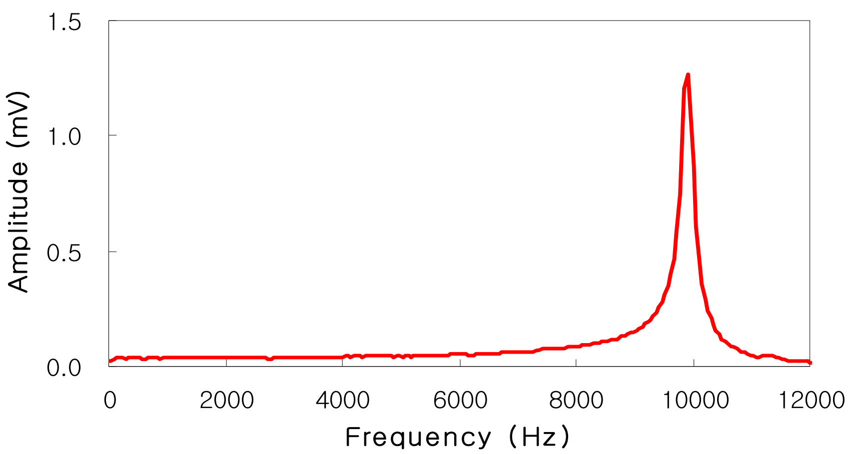


Figure 4. A typical resonance frequency obtained from FFT analysis.

LDWT (Light deflector weight test) also was performed to investigate stiffness of CLSM in vertical direction. The LDWT was designed and developed to verify stiffness or degree of compaction of the soil in the field. In this study, LDWT made by GERHARD JORN (ZFG 2000 model) was used to get stiffness of the CLSM in vertical direction. The measured stiffness of the CLSM is compared to that obtained from the PMT. A schematic view of the LDWT test is shown in Figure 5. Falling height of the weight of 10 kgf is 0.7 meter. Average measured stiffness obtained by three continuous tests on one spot position is considered as the stiffness (E_{vd}) at the position. The stiffness is calculated based on the following theoretical equation:

$$E_{vd} = 1.5r \frac{\Delta\sigma}{\Delta s}$$

where r = radius of the plate, $\Delta\sigma$ (Mpa) = 0.1 in case of 10 kgf weight, Δs =settlement of the plate in mm.

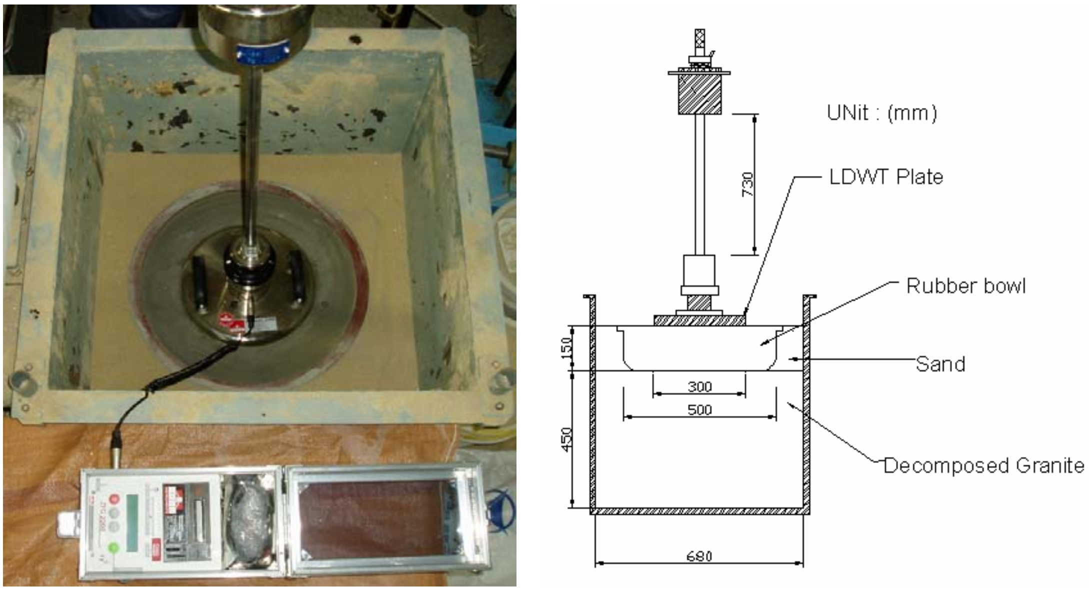


Figure 5. Schematic view of LDWT test.

In addition, after well mixed CLSM with a designed mixing ratio was poured into a small plastic cylindrical container (Height = 500mm, Diameter=320mm) that was used as a mold. The large plastic mold holding the CLSM was placed in a cylindrical confining chamber before curing started (Figure. 6). Then PMT probe was placed into the center of CLSM in the plastic mold in the confining chamber. PMT tests were performed to get information such as effects of strain dependency and stress level on stiffness of the CLSM.

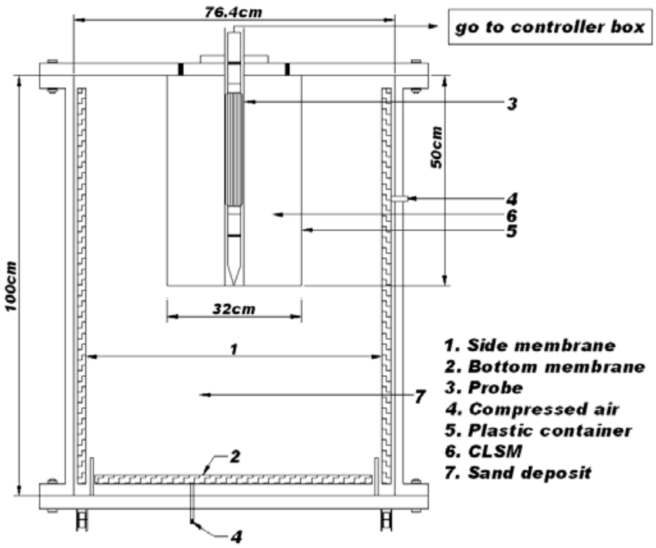


Figure 6. PMT schematic in confining chamber.

In usual, the pressumeter test is used to get stiffness of the ground in horizontal direction. A relation graph between pressure (p) applied into the probe of the pressuremeter and increased volume ($\Lambda V / V_o$) of the probe is obtained by performing the test. The increased volume can be easily converted to radial strain ($\Lambda R / R_o$) of the probe as shown in Figure 7. Therefore, a pressure (stress) – strain relation of the ground soil can be made form a test. Stiffness of the CLSM is obtained by measuring slope of the graph illustrated in Figure 7. Initial modulus (E_o) is initial tangent of the slope. Unloading-reloading modulus (E_R) is defined as the average slope of the unloading and reloading parts of the graph.

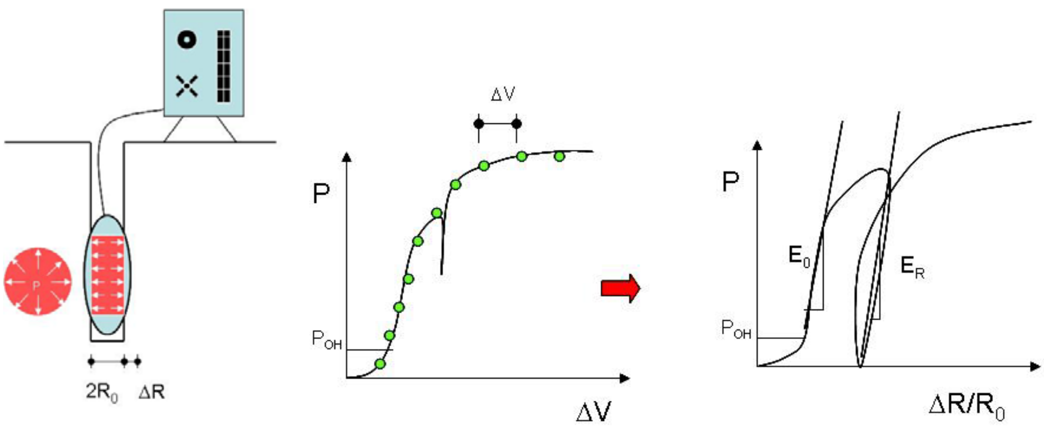
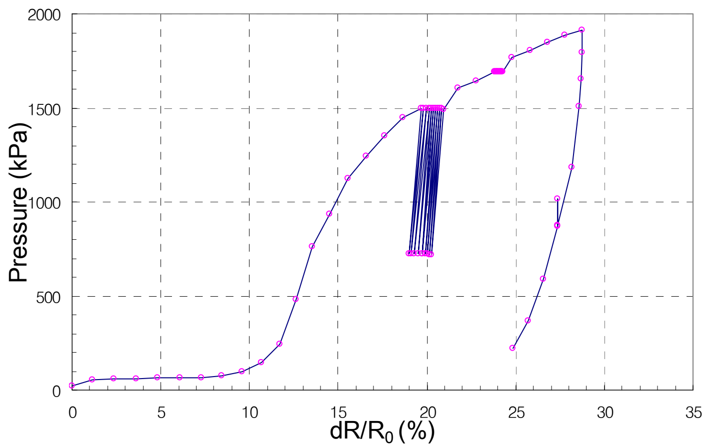


Figure 7. A schematic view of PMT test and its concept of obtaining data

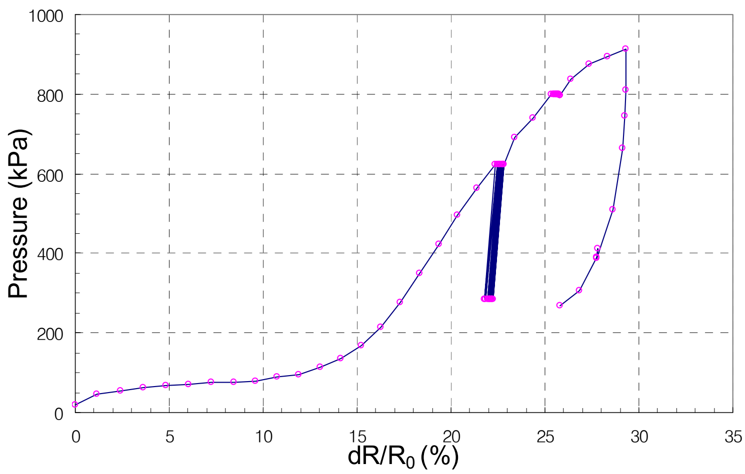
Figure 8 shows test procedure of PMT adapted in the laboratory where a steel confining chamber was used to simulate confining pressure to the CLSM compound in the model

ground. Figure 9 illustrates typical PMT test results obtained from CLSM compound constructed in the model ground.

Figure 8. PMT test of CLSM in confining chamber



(a)



(b)

Figure 9. Typical PMT data obtained: (a) weathered granite soil CLSM, (b) sand CLSM

Effects of strain dependency, stress level and loading rate on the stiffness can be simulated and tested using PMT since the CLSM should be placed in lower part of the road. In order to simulate these effects a specially designed test procedure of pressuremeter were adapted in this study [2]. A unified form of the stiffness of materials in CLSM backfill considering strain level, stress level, repetition of load and load duration can be represented as follows [2]:

$$E = \frac{1}{\frac{1}{K}\left(\frac{\theta}{P_a}\right)^{-n_\theta} + b\varepsilon}\left(\frac{t_1}{t_0}\right)^{-n_t} N^{n_C}$$

In order to use the above equation for evaluation of stiffness modulus of CLSM backfill or subgrade in the field, the pressuremeter parameters (K, n_θ, n_t, n_c) in the equation must be obtained using PMT. Model tests using calibration chamber were considered in this study for validating the proposed method using PMT.

4. TEST RESULTS

UCS of CLSM was obtained from UCT test at the curing age of 28 days after mixing. UCS increased with increase of Porland cement as expected as shown in Figure 10.

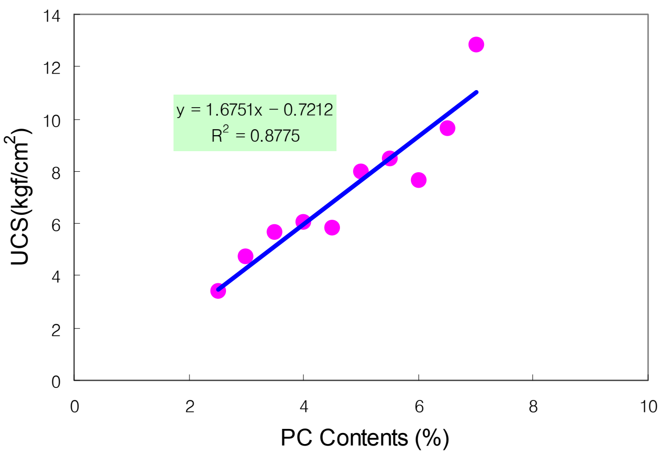


Figure 10. UCS of CLSM with increase of Portland cement contents

However, there were no big differences in UCS between the CLSM made with weathered granite soil and the CLSM with sand at the same mixing ratio of Portland cement. ACI has offered a criterion for CLSM based on UCS in which UCS has divided into three groups: 1) less than 7 kgf/cm^2, 2) 7-21 kgf/cm^2, and 3) over 21 kgf/cm^2. These UCS ranges are offered for grouping capability of excavation into three categories: 1) excavation by man, 2) machine excavation, and 3) excavation

impossible by machine. It was verified that all designed mixing ratio of CLSM with use of weathered granite soil and standard sand was good enough for excavation. This means that the weathered granite soil excavated in the field can be mixed as CLSM that can be used as backfill material because the CLSM proved to have proper UCS with enough flowability. Specially, in the pressuremeter test, the CLSM made with weathered granite soil shows more than twice elastic modus (E_{FF-RC}) compared to that made with standard sand as shown in Figure 11.

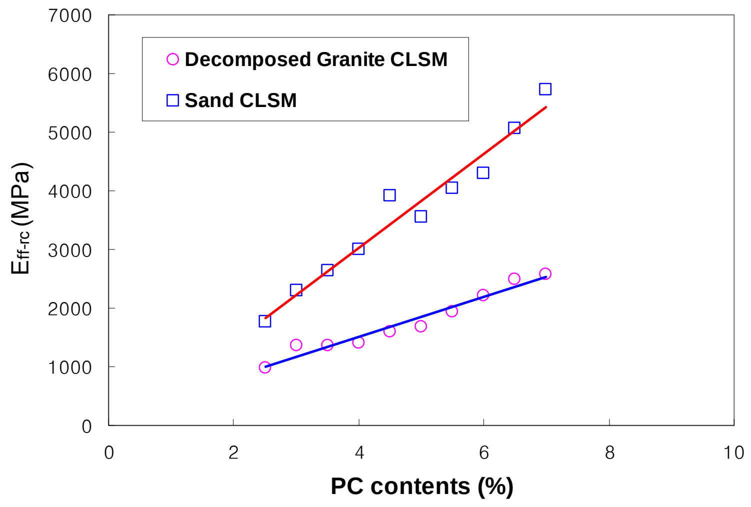


Figure 11. Elastic modulus measure by FF-RC

5. CONSLUSIONS

It is verified in this study that the CLSM made with weathered granite soil can be used as replacing material for the backfill soil because it can provide higher stiffness comparing to the backfill soil so that the CLSM can diminish vertical differential settlement and faulting within limit in case of highways.

ACKNOWLEDGEMENTS

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